Analysis of the relationship between fish habitat classifications and topological lake units

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ABSTRACT

The goal of this study was to objectively assess subjective fish habitat classification systems using topological measurements of lake units such as depth, slope, and a range of fetch indices from a set of small lakes (<25 ha). This study is in attempt to develop a predictive modelling tool for assessing fish habitat from measurements easily obtained from bathymetric maps.

The spatial distribution of both substrate and cover (wood and macrophytes) were mapped for each of the lakes. At systematically selected sampling points, values were calculated for depth, slope and a range of fetch indices. Discriminant functions analyses (DFA) were performed to predict substrate and cover classifications separately in the littoral zone and in the entire lake.

There was poor success in predicting field classifications of both substrate and cover using topological units as predictors. For substrate, the more simplified the classes were, the higher the success of predicting classification. The functions for predicting substrate in lakes are not transferable between lakes.

The sizes of the study lakes were too small to determine the effects of wind driven forces. Only a small portion of the lakes are affected by wind driven forces at least some of the time. In the future, this analysis should be repeated on lakes with larger areas to determine both the effect of wind driven forces and the influence of lake area on substrate distribution.

RÉSUMÉ

L'objectif de la présente étude était de faire une évaluation objective des systèmes subjectifs de classification de l'habitat du poisson en se servant de paramètres topologiques de lacs individuels, comme la profondeur, la pente et une gamme d'indices de portée provenant d'une série de petits lacs (< 25 ha) en vue de mettre au point un outil de modélisation prédictive pour évaluer l'habitat du poisson à partir de mesures faciles à obtenir de cartes bathymétriques.

Nous avons établi des cartes de la distribution spatiale du substrat et de la couverture végétale (arbres et macrophytes) pour chaque lac expérimental et nous avons mesuré la profondeur, la pente et une gamme d'indices de portée à des points d'échantillonnage choisis systématiquement. Puis nous avons utilisé des analyses

discriminantes (AD) pour prédire séparément dans quelle catégorie d'inscrivait le substrat et la couverture végétale de la zone littorale et du lac entier.

L'utilisation d'unités topologiques comme variables explicatives n'a pas donné de bons résultats pour ce qui est de prédire la classification sur le terrain du substrat et de la couverture végétale. Dans le cas du substrat, plus simplifiées étaient les classes, plus grand était le succès de la prédiction de la classification. Par contre, les fonctions servant à prédire le substrat d'un lac ne sont pas transférables à un autre.

Il nous a été impossible d'établir les effets des forces dues aux vents parce que les lacs expérimentaux étaient trop petits. Ces forces ont une incidence sur une petite partie des lacs au moins pendant un certain temps. Une nouvelle analyse portant sur des lacs de plus grande superficie devrait être faite à l'avenir en vue d'établir les effets de ces forces et l'incidence de la superficie d'un lac sur la distribution du substrat.

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INTRODUCTION

The relationship between energy inputs into a lake and substrate distribution are hard to define and quantify; this is especially true in small lakes with effective fetch values less than 5 km where wind and wave influences are limited (Hakanson and Jansson 1983; Cyr 1998). Topological lake units such as slope, depth, and fetch indices are known to have an influence on sediment distribution in lakes. Hakansan and Jansson (1983) and Franzin (1999) have described an erosion, transport, and deposition concept, whereby hydraulic processes based on energy from wind-driven waves determine substrate composition in littoral area of lakes (Franzin 1999).

Cyr (1998) investigated the effects of wave disturbance and slope on sediment characteristics in the littoral zone of small lakes. She found that the depth of wave-induced sediment resuspension increases with increasing wind exposure and with decreasing size and density of sediment particles. Direct wave action, and higher wind energy can resuspend fine sediments (Cyr 1998) and transport larger particles, creating a gradient in particle size distribution (Sly 1978).

An understanding of the effect of energy inputs into a lake, and therefore the contributions of topological features on particle distribution, would allow for predictive modelling of fish habitat features. Traditional fish habitat assessments, involving data collection in the field, can be unreliable, labour intensive, and costly. Several problems have been documented concerning the reliability of fish habitat data collection. Error in assessment can be introduced from several sources such as investigator experience or training (Roper and Scarnnecchia 1995), interpretation of variables to be measured and observer subjectivity (Kondolf and Li 1996; Stanfield and Jones 1998). The ability to predict fish habitat using topological lake units would provide a predictive modelling tool for fish habitat managers and reduce inherent subjectivity of current assessment methods.

The goal of this study was to objectively assess subjective fish habitat classificatio' systems using topological measurements of lake units such as depth, slope, and a range of fetch indices. Analyses are based upon the erosion, transport, and deposition concept and applied to the fish habitat distribution of a set of small lakes (<25 ha) in Northern Ontario. This study is in attempt to develop the predictive modelling tool for assessing fish habitat from measurements easily obtained from bathymetric maps.

METHODS

Study Area

Five small lakes (<0.25 km^2) were used for this analysis, Little Turkey, Lower Batchawana, Upper Batchawana, and Wishart Lakes, all located within the Turkey Lakes Watershed (TLW) (84°25'W, 47°03'N) approximately 50 km north of Sault Ste. Marie, and Quinn Lake (84°13'14"W, 46°43'52"N) ~ 50 km SE of TLW. All field sampling on the lakes took place been July 1 and September 5, 1998.

Habitat Assessment

Maps of the spatial distribution of substrate, macrophyte, and wood coverage were completed on all of the five lakes using the littoral zone cruise habitat assessment method (Frezza 2001) (area between shore and the 2 m contour). Substrate was classified into eight different habitat types by particle size (Table 1) and macrophytes into seven categories according to growth forms (Table 2). Pieces of coarse woody material (greater than 10 cm diameter) were counted in approximately every 20-50 m of shoreline distance from shore to the 2 m contour. In a GIS, the shoreline of each lake was divided into sections where the wood was counted, and the corresponding wood count assigned to each section. From a previous habitat assessment completed on these study lakes using a transect sampling method (Frezza 2001), the average distance from shore that wood was present was calculated. A buffer zone, using the average distance wood was found from shore as its width, was placed parallel to the shoreline segments to create polygons. The density of wood within each polygon was calculated (number of pieces of wood per $metre^2$ of shoreline). Wood densities within polygons were grouped into five classes: 0 pieces/m^2; 0.01-0.5 pieces/m^2; 0.51-1.5 pieces/m^2; 1.51-2.5 pieces/m^2; and >2.5 pieces/m^2. The macrophyte and wood distribution maps were overlaid to create a distribution of cover with unique polygons of macrophyte and wood density combinations.

Topological Units

Using a GIS, the littoral area of each lake (from shore to the 2 m depth contour) was divided into 2 m^2 grids and the offshore area (>2 m depth) into 10 m^2 grids with respect to the georeferencing and hence some littoral grids overlapped the shoreline and some offshore ones the littoral zone. We systematically selected every 5^{th} grid in the nearshore area and every grid within the offshore area as a sample location, using the centroid of each grid as a sample point. The substrate in the offshore zone was assumed to be mud and hence only depth varied among offshore grids.

A range of fetch indices for each sample point was calculated using an Arc-info procedure. These included the minimum, maximum, and average fetch, the minimum, maximum and average effective fetch, and the effective fetch in the strongest wind direction (292.5°). The strongest wind direction was determined from a time-series of wind speed and direction observations gathered at TLW.

Bathymetric maps with 0.5 m contour intervals were used to interpolate surface maps of depth. The depth at each sample point was determined, in addition to the habitat class at each point. The slope at each grid point was calculated by dividing the depth by the minimum effective fetch, giving the percent rise from shore. This slope index is the simplest computable and assumes a lake is conic with respect to each grid point. The bathymetric survey data was acquired digitally by a unit of the Ontario Ministry of Natural Resources (OMNR) and provided to the study.

Analysis

To reduce the number of variables cosnsidered, a principal component analysis (PCA) was performed on the dataset from Little Turkey Lake. Variables that contributed the least to the principal components variates were eliminated from further analysis unless their exclusion meant that class of variable was excluded. Variables that were selected were used in a discriminant function analysis (DFA) to predict the habitat classification at each sampling point. DFA's were performed to predict substrate classification and cover (macrophyte and wood combined) classification separately within the nearshore area and within the entire lake.

Using the substrate dataset, three different habitat classification schemes were used for the DFA: 1) all the original substrate classes (Table 1); 2) general size groupings of fine (sand and muck), medium (rubble and gravel), and large (bedrock and boulder); 3) large particle sizes separate from all others (bedrock, boulder, and others). This was done to determine if the success of predicting habitat classification from topological lake units increased with a simplification of the classification scheme. To further clarify the results from the DFA on the substrate dataset, approximately 1000 sample points were systematically selected (every Nth record) from each lake to provide a roughly balanced sample and compiled into one dataset (n=4492). A DFA was performed to predict classification of large particle size groupings to determine if the same topological units can be used as predictive tools on all the lakes.

The success of classifying habitat categories using a DFA does not take into account the possibility of chance agreement between field classifications and predicted

classifications. Cohen's Kappa statistic (Cohen 1960) was used to determine the success of predicting habitat classification, for both substrate and cover, corrected for chance agreement. Kappa values can be interpreted as percentages or proportion of agreement. A value of 0 indicates no agreement between predicted classification and field classification whereas a value of 1 indicates perfect or 100% agreement.

Hakanson (1982) found that distribution of lake bottoms is governed by an energy, slope, and form factor which can be expressed as a dynamic ratio (DR):

$$DR = \frac{\sqrt{a}}{\overline{D}}$$

where a is the lake area (km^2), and $\overline{D}$ is the mean depth (m). The DR can be used as a tool to determine which lakes are susceptible to sediment disturbance by wind-driven waves (Bachmann *et al.* 2000). We calculated the DR for each lake and determined what proportion of the lakes are susceptible to sediment disturbance at least some of the time from the empirical equation provided by Bachmann *et al.* (2000):

Percent of the lakebed disturbed some of the time = 12.4 + 109 x DR

The dynamic ratio (DR) was plotted against the percent classification success of each of the lakes (substrate and cover) to determine any trends.

RESULTS

The number of variables used was reduced from nine to five based on the contribution of each variable to the principle component variates (Table 3) thereby reducing the number of fetch variables. Depth and slope were retained as they had previously been shown to be useful variables. The variables selected for use in the DFA were depth, slope, minimum effective fetch, maximum effective fetch, and effective fetch in the strongest wind direction. Although slope values had a lower contribution to the principal component variates (Table 3) than other variables, it was not eliminated from further analyses. Slope is a contributing factor to sediment distribution (Cyr 1988) and therefore would be a valuable variable to include in the DFA for predicting habitat classification. All fetch variables (minimum, maximum, and average fetch) were eliminated from further analyses even though they had a larger contribution to the principal component variates. Instead, minimum and maximum effective fetch values were used since they provide a more rounded measure of distance to shore. Average effective fetch was excluded due to its redundancy with the other effective fetch values.

The results of the DFA for predicting substrate classification are summarized in Table 4 for the littoral area and Table 5 for the entire lake. Classification success was poor for most habitat classes, with the exception of the large size substrate classes. As the substrate classes were simplified, the classification success of the DFA increased (Table 4 and 5). Upper Batchawana Lake was the only lake that had high classification success when using all of the original substrate classes (from Table 1). When the presence of chance agreement between the field classifications and the predicted classifications were removed through the use of the Kappa statistic, overall classification success was reduced for each of the lakes. The high success rate of predicting substrate in Upper Batchawana Lake was reduced by more than half, resulting in a low classification success.

An example of a classification matrix from the DFA is given in Table 6 using Little Turkey Lake and general size groupings of fine, medium, and large as habitat units. In general, the success of predicting habitat units from topological lake units was higher for large particle classes than the medium and smaller particle classes (Table 6). With an increased simplification of habitat units, the classification success of predicting habitat units using the topological variables increased, especially for Wishart Lake (Table 4). This can be seen in Figure 1, an example of the distribution of factor scores from the DFA of Little Turkey Lake using bedrock, boulder, and other classes. Although there is overlap between the habitat classes, there are separate groupings for the other classes and boulders (Figure 1).

The success of predicting substrate classification was lower for all the lakes than for the individual lakes. There was approximately a 50% classification success for each of the substrate classes (Table 7). This indicates there is no consistent pattern of predicting substrate for all of the lakes and there are unique processes occurring within individual lakes.

Similar to substrate classification, there was, in general, low success of predicting classification of cover from the five topological units (Table 8). The highest success of cover classification was for Little Turkey Lake (63%; Table 8). There was a decrease in classification success after the Kappa analysis, on some lakes by half (Table 8).

The dynamic ratio of all lakes was under 0.80 (Table 9), falling in the range of values which experience a linear decrease in the lake area disturbed at one time or another (Bachmann *et al.* 2000). Bachmann showed that occasional extreme wind events are what shape much of the sediment distribution and redistribution in larger

lakes. These study lakes do not appear to be greatly affected by wind driven forces at least most of the time. The shallowest lake, Wishart Lake, has the greatest amount of area (38.8%) that might be disturbed some of the time (Table 9).

DISCUSSION

Slope, depth, and a range of fetch indices, used to predict fish habitat distribution in small lakes, are representative of wind driven energy inputs into lake systems. Slope of the lake bottom will influence the amount of sliding of substrate particles, where steep slopes significantly increase sediment distribution (Sly 1978; Rowan et al. 1992). The amount of sorting of substrate particles is in part attributed to water depth. Shallow areas are subjected to wave action causing sediment resuspension and may be areas of either sediment erosion or transport. Fetch indices provide indirect measures of wind exposure, or the potential total effect of waves. Exposure, where fetch and wind energy are integrated, is considered to be a major factor affecting both plant and substrate distributions in lakes (Keddy 1982) Although all three variables, slope, depth, and fetch, play a role in fish habitat distribution in lakes, they do not act independently. Since their contributions are interconnected, in this analysis we have incorporated all the variables to investigate their combined contributions.

Although topological lake units have been found to affect substrate and vegetation distribution, we found poor success of predicting fish habitat classification when using slope, depth, and fetch indices as predictors. When attempting to predict all substrate classes (Table 1), there was a low success rate, with a classification success of less than 50% in more than half the lakes (Table 4). As the substrate classes became more simplified, the ability to predict these classes from the topological features increased. For two of the lakes, Upper Batchawana and Quinn, the success of classifying substrate reached over 70% with the most generalized classes of bedrock, boulder, and others (Table 4). As seen in the example classification matrix from the analysis of Turkey Lake data (Table 6), the substrate category with the lowest classification success is fine particles, followed by medium particles, and the large particles had a relatively higher classification success of 74%. When these classification are grouped into bedrock, boulder, and other, the habitat classes with poor classification success (fine and medium) are grouped together as one, therefore lumping the error into one class and raising the overall success rate of predicting habitat classes using topological units. Although there were high success rates of predicting the large group classes, a large

portion of this success can be attributed to chance agreement (Table 4 and 5). The success of predicting habitat classification in Upper Batchawana was reduced from 80+% to 40-% for the different categories of substrate classification (all classes; size groups; large groups).

When the offshore areas were included in the analyses, predicted classification success increased slightly over the situation when only the nearshore area was considered. In the offshore area there is only one habitat class, the mud zone. A higher success rate of predicting the mud zone was expected since depth was a primary determinant but overall did not increase prediction success for other habitat classes.

In addition to low prediction successes for substrate classification, the topological criteria for predicting membership in the most generalized classes were not transferable between the lakes. For all of the lakes individually, there was a relatively high classification success with prediction of the large group classification (bedrock, boulder, and others). When samples from all the lakes were combined, the success of predicting substrate classification from the topological units was only 50% (Table 7) lower than for any of the lakes individually (Table 4) pointing to lake specific patterns of variable associations.

Our attempts to predict cover (vegetation and wood combined) classifications in lakes from topological units had low success rates, similar to substrate classification. The same pattern was seen where some of the lakes had a high predicted classification success rate and other lakes a low success rate. Again, when the offshore samples were added to the analysis, the classification success increased slightly.

Hakanson (1982) developed the dynamic ratio (DR) which summarizes how the areal distribution of lake bottom dominated by deposition, erosion and transport is governed by an energy and morphometric factors. Bachmann *et al.* (2000) used this dynamic ratio to create a morphometric index that calculates the potential for wind disturbance of sediments in lakes. This index was applied to the lakes in this study and we found that only small portions of their lakebeds are disturbed by wind driven forces some of the time. The lake most affected by wind driven forces was the shallowest of the lakes, Wishart, where less than 40% of its area is disturbed some of the time. The area of these study lakes was too small for energy inputs to influence the distribution of substrate. In smaller lakes there may be other processes, such as glacial geology, determining distribution of fish habitat. In addition, ice scouring in winter may also be a factor in these north temperate lakes.

The relationship between energy inputs into a lake and its substrate distribution is hard to define and quantify, particularly in small lakes (Hakanson and Jansson 1983) similar to the ones used in this study. Other studies in larger lakes have shown that wind energy can transport larger particles (Sly 1978) and resuspend fine sediments (Cyr 1998). The results from of study lakes indicate a lower bound to potential impact of the wind energy impacts on substrate distribution. Further, since these study lakes are on the Canadian Shield and have low sediment inputs, the supply of sediment may also be an important factor. In the future, it would be advantageous to repeat this analysis on wider range of lake areas. This would clarify the influence of lake area and how it constrains substrate distribution from energy inputs.

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Table 1. Definition of substrate types revised from Lester *et al.* (1998).

Substrate types	Definition
Bedrock	Exposed rock, no overburden
Boulder	>25 cm
Rubble	8 - 25 cm
Gravel	0.2 - 8 cm
Sand	<0.2 cm
Silt/Muck/Detritus	Inorganic, soft and decaying organic
Clay	Inorganic without structure
Other	Does not fit into any of the other categories

Table 2. Definitions and descriptions of macrophyte types (Frezza 2001).

Macrophytes	Description
Grass-like	Tall thin plants, slender leaves, no lateral foliage
Carpet	Creating bottom cover
Cover rooted	Providing surface cover, rooted
Cover, no roots	Providing surface cover, not rooted
Leafy, extending to surface of water	Leafy foliage, extending vertically to the water's surface
Leafy, extending no further than half way through water column	Leafy foliage, extending vertically only half way up the water column

Table 3. Results from a principal components analysis using data from Little Turkey Lake. The table lists the contributions from each variable to the principal component variates.

	Principal component variates	
	1	2
Eigenvalue	4.91	2.51
% Variance explained	48.54	35.22
Slope	0.20	-0.06
Depth	0.14	0.90
Min. fetch	0.09	0.96
Max. fetch	0.95	-0.03
Average fetch	0.96	0.19
Min. effective fetch	0.09	0.96
Max. effective fetch	0.98	0.03
Ave. effective fetch	0.96	0.19
Effective fetch 292°	0.48	0.24

Table 4. Classification success of a DFA to predict substrate classes in the littoral zone area from five topological units. Included is the classification success once chance agreement is removed (Kappa value).

Lake	Classification Success (%) (DFA/Kappa)					
	All classes		Size groups		Large groups	
Little Turkey	34	14	44	16	52	11
Wishart	48	11	56	21	69	9
Lower Batchawana	50	18	60	17	56	19
Upper Batchawana	80	32	83	37	87	41
Quinn	67	9	72	12	73	7

Table 5. Classification success of a DFA to predict substrate classes in the entire (littoral and offshore) lake from five topological units. Included is the classification success once chance agreement is removed (Kappa value).

Lake	Classification Success (%) (DF/Kappa)					
	All classes		Size groups		Large groups	
Little Turkey	48	37	56	43	61	44
Wishart	50	22	58	32	71	32
L. Batchawana	52	24	61	26	58	27
U. Batchawana	81	45	84	52	87	56
Quinn	68	32	74	38	74	36

Table 6. Classification matrix from the DFA indicating the success of predicting substrate classes on Little Turkey Lake at sampling points using topological variables. Substrate classes from field classification are in rows and the predicted classification in columns. Numbers in the diagonal are successful predictions of habitat classification.

	Fine	Medium	Large	% Correct
Fine	1023	755	954	37
Medium	393	663	227	52
Large	34	48	231	74
Total	1450	1466	1412	44

Table 7. Classification matrix from the DFA indicating the success of predicting substrate classes at sampling points from all the lakes using topological variables. Substrate classes from field classification are in rows and the predicted classification in columns. Numbers in the diagonal are successful predictions of habitat classification.

	Bedrock	Boulder	Other	% Correct
Bedrock	27	9	16	52
Boulder	42	110	87	46
Other	993	1136	2072	49
Total	1062	1255	2175	49

Table 8. Classification successes of a DFA to predict cover classes in the nearshore zone and the entire lake from five topological units. Included is the classification success once chance agreement is removed (Kappa value).

Lake	Classification Success (%) (DF/Kappa)			
	Nearshore		Entire lake	
Little Turkey	63	36	65	52
Wishart	50	30	53	37
L. Batchawana	28	18	30	21
U. Batchawana	52	22	41	25
Quinn	18	13	23	20

Table 9. The area, mean depth, dynamic ratio, and percent of area disturbed some of the time by wind driven forces for each lake.

Lake	Area (km^2)	Mean depth (m)	Dynamic ratio	% of lake disturbed some of the time
Little Turkey	0.21	6.17	0.07	20.6
Wishart	0.19	1.82	0.24	38.8
L. Batchawana	0.05	3.44	0.07	19.6
U. Batchawana	0.06	3.19	0.08	21.0
Quinn	0.07	4.33	0.06	19.0

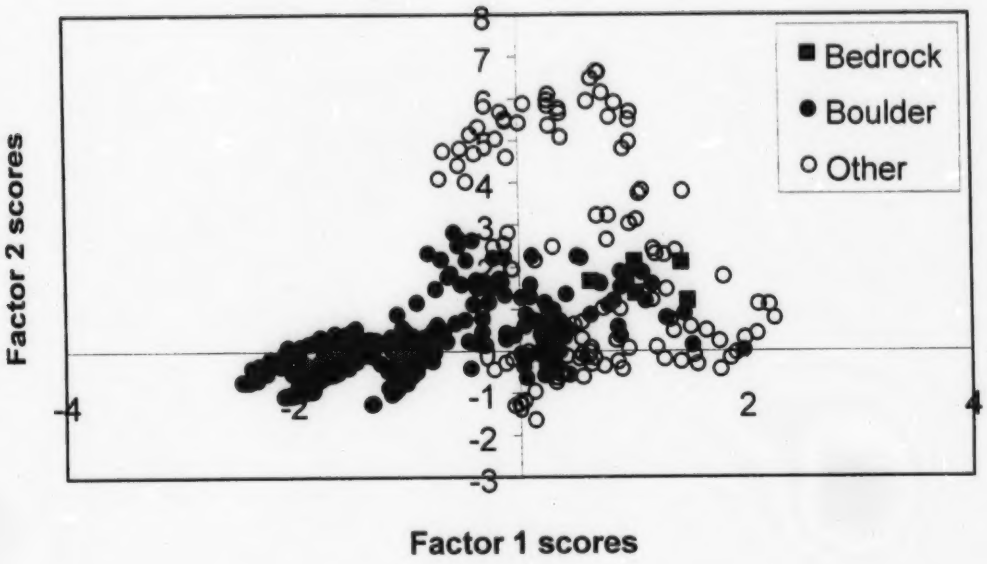

Figure 1. Factor scores from the DFA of Little Turkey Lake using habitat units of bedrock, boulder, and other. The classification success of each habitat unit was 75% bedrock, 71% boulder, and 54% other. The total classification success was 55%.